Intraoperative navigation evaluation of tibial translation after resection of anterior cruciate ligament remnants

（術中ナビゲーションを用いた遺残前十字靭帯の脛骨制動性に及ぼす影響の検討）

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Abstract

Purpose: This study aimed to assess knee laxity before and after resection of the anterior cruciate ligament (ACL) remnants, using a computer navigation system. Methods: This prospective study included 83 knees undergoing primary navigated ACL reconstruction. ACL remnants were classified into 4 morphological types based on the arthroscopic findings as follows: type 1, bridging between the posterior cruciate ligament and tibia; type 2, bridging between the roof of the intercondylar notch and tibia; type 3, bridging between the lateral wall of the intercondylar notch and tibia; and type 4, no substantial ACL remnants. Anterior tibial translation (ATT) and range of internal-external rotation of tibia (total rotation) at 15°, 30°, 45°, 60°, 75°, and 90° of knee flexion was measured before and after resection of the ACL remnants using the additional functions of the navigation system. Results: The different morphological types of the ACL remnants were as follows: type 1, 12 knees; type 2, 16 knees; type 3, 51 knees; and type 4, 4 knees. There were no significant differences in the mean ATT before and after resection at any knee flexion angle in types 1, 2, or 4. In type 3, the mean ATT at 15° of knee flexion before resection significantly increased after resection. There were no significant differences in the mean total rotation before and after resection at any knee flexion angle in each type. Twelve knees (14.5%) in type 3 showed an increased ATT of 3 mm or more after resection of the ACL remnants. Conclusions: The present study suggests that the ACL remnant does not play a major role in stabilization of the knee.

Although type 3 ACL remnants significantly decreased anterior knee laxity in the knee extension position, the knee stability provided by the ACL remnants was not adequate.

Introduction

The anterior cruciate ligament (ACL) is known to be an important stabilizer of the knee joint and is the restraint for anterior tibial translation (ATT) and rotation.[1] ACL reconstruction has been accepted as the treatment of choice for ACL-deficient knees to eliminate excessive ATT.[2,3] Tunnel malposition in ACL reconstruction is one of the most common causes of revision ACL reconstruction[4,5]. To decrease technical error such as tunnel malposition, a computer navigation system has been introduced in ACL reconstruction.[6–9] Initial applications of this new technology focused upon improving the accuracy and repeatability of tunnel placement. More recently, the computer navigation system has been increasingly used as a quantitative measurement tool to assess knee kinematics before and after ACL reconstruction.[9-12]

Arthroscopic observation of torn ACLs during ACL reconstruction often reveals that several types of ACL remnants exist in the intercondylar space. In some cases, the ACL remnants bridge the femur and tibia, the femoral attachments of the ACL remnants are slightly different from the original positions, and the tension is attenuated. This type of ACL remnant helps to prevent anterior knee laxity to a certain extent. Recently, some surgeons have focused on the treatment of partial ACL tears with the use of individual augmentation. Saving the intact parts of the ACL and the ACL remnants may have several advantages; however, the biomechanical function of the ACL remnants remains unknown. The purpose of this study was to assess knee laxity before and after resection of the ACL remnants, using additional functions of the navigation system. The hypothesis in this study was that the ACL remnants do not play a role in stabilization of the knee.

Methods

From June 2008 to December 2009, a consecutive series of 120 patients with ACL deficiency underwent ACL reconstruction at our hospital using the OrthoPilot ACL version 2.0 navigation system (B. Braun Aesculap, Tuttlingen, Germany), an image-free, wireless system that does not require preoperative CT or intraoperative fluoroscopy was used. Of these patients, 83 were included in this study. Exclusion criteria were revision ACL reconstruction, severe collateral ligament injuries, posterior cruciate ligament injury, anterior or posterior horn tear or bucket-handle tear of the menisci, and navigation fixator loosening during surgery. The diagnosis of ACL deficiency was determined by either Lachman test, anterior drawer test, or pivot shift test of ≥ grade 1+, and KT-1000 arthrometer (MedMetric, San Diego, CA) side-to-side difference of ≥ 3mm. MRI imaging was also used to determine the ACL tear, and to look for signs of any associated injuries in the knee. All patients received either double-bundle reconstruction with a hamstring tendon graft or single-bundle reconstruction with a patellar tendon autograft. There were 43 male and 40 female patients with a mean age of 26.3 years (range, 12–58 years). ACL reconstruction was performed a mean of 34 weeks after the injury (range, 1 week–10 years). There was a tear in one or both menisci in 61 of the 83 knees, involving the medial meniscus in 7, the lateral meniscus in 19, and both menisci in 35.

Arthroscopic Evaluation

All surgeries were performed under general anesthesia, and the configuration of the ACL remnants and their attachments to the femur and tibia were characterized. The intercondylar notch was carefully inspected using a probe to identify any remaining ACL fibers. The attachment of the ACL remnants was classified from the video of the arthroscopy by an orthopaedic surgeon who did not participate in the surgery. The ACL remnants were classified into 4 morphological patterns as follows: type 1, bridging between the posterior cruciate ligament and tibia; type 2, bridging between the roof of the intercondylar notch and tibia; type 3, bridging between the lateral wall of the intercondylar notch and tibia; and type 4, no substantial ACL remnants. (Arthroscopic findings, Figure 1a–d; Schematics, Figure 2a-d) Meniscal pathology was also assessed. All meniscal treatments were performed after testing for anterior laxity to avoid any influence on the test results.

Knee stability evaluation using a navigation system

After arthroscopic evaluation of the ACL remnants, the arthroscope was removed and the arthroscopy fluid content in the knee joint was evacuated as far as possible. Then, laxity testing was performed using the additional functions of the navigation system. This navigation system can show not only the intraoperative tunnel position, but also knee kinematics, such as anterior-posterior (AP) displacement and internal-external rotation of the tibia both before and after ACL reconstruction. The accuracy of this system is extremely precise and the cameras can track the position of the instruments to within less than 1 mm and less than 1°.[13] All navigation processes (registrations of knee kinematics and anatomic landmarks) and knee laxity evaluation were performed by a single surgeon. Manual maximum anterior load was applied to the tibia in neutral rotation, and the ATT at 15°, 30°, 45°, 60°, 75°, and 90° of knee flexion was measured. Internal and external rotational forces were also applied manually, and total range of internal-external rotation of tibia (total rotation) at same knee flexion angle was also measured. After measurement, the arthroscopy was resumed and the ACL remnants were resected. After resection of the ACL remnants, ATT was measured again in the same manner. The study design was approved by the ethics committee in our institution, and all patients provided informed consent to participate in this study.

Statistical Analysis

All results are expressed as mean ± standard deviation. ATT and total rotation at each knee flexion before and after resection of the ACL remnants in each type was compared with the paired t-test. A one-way analysis of variance was used for multiple comparisons among the 4 types, with the degree of increased ATT at each knee flexion after resection (Δ ATT), and Tukey test for post hoc analysis was performed. The arthroscopic findings of patients with increased ATT by 3 mm or more at any angle after the resection were examined. The significance level was set at $P < .05$. SPSS software (version 12.0; SPSS, Chicago, IL) was used for statistical analysis.

Results

Results were obtained for all 83 patients. There were no complications due to the ACL reconstruction procedure or the navigation process.

The different morphological types of the ACL remnants were as follows: type 1, 12 knees (14.5%); type 2, 16 knees (19.3%); type 3, 51 knees (61.4%); and type 4, 4 knees (4.8%). There were no statistical differences between the 4 types with respect to age, gender, length of time from injury, or meniscal pathology.

There was no significant difference in the mean ATT before and after resection at any knee flexion angle in type 1, type 2, and type 4. The mean ATT at 15° of knee flexion angle before resection of type 3 ACL remnants significantly increased after resection ($P = .03$), and there was no significant difference in the mean ATT at other knee flexion angle. There was no significant difference in the mean total rotation before and after resection at any knee flexion angle in each type. The data of ATT and total rotation before and after resection of the ACL remnants are summarized in Table 1, Table 2, and Figure 3a-d. No significant differences in ΔATTs were observed within each type at any knee flexion angle. (Figure 4)

Twelve knees (14.5%) showed increased ATT of 3 mm or more after resection of the ACL remnants at one or more knee flexion angles. Six knees showed such an increase at either 15° or 30°, 4 knees at either 60° or 75°, and 2 knees between 15° to 60°. Although these ACL remnants were of the type 3 morphological pattern, they were attached to a non-anatomical position at the lateral intercondylar wall. In the two knees that showed a clear increase between 15° to 60° of the knee flexion, the remnants were attached slightly anterior to the original position at the intercondylar notch in the arthroscopic view, and the ACL fibers were strained.

Discussion

In this study, the knee stability by the ACL remnants was assessed using a navigation system. In types 1, 2, and 4, there were no significant differences in the ATTs before and after resection of the ACL remnants. However, in type 3 the mean ATT at 15° of knee flexion before resection of the ACL remnants was significantly increased after resection. No significant differences in ΔATT and total rotation were observed within each type at any knee flexion angle. Although, increased ATT (≥3 mm) after resection of the ACL remnants attached to the lateral intercondylar notch was observed in 12 knees (14.5%). Crain et al.[14] assessed variations in the ACL scar pattern and the relationship between the scar pattern and anterior laxity in 48 patients. They evaluated the anterior knee laxity before and after ACL remnant debridement using a KT-1000 knee arthrometer. Fourteen of 48 knees (29%) loosened more than 2 mm after ACL remnant debridement. After resection of the ACL remnant attached to the femur, mean loosening of 3.9 mm occurred. They suggested that ACL remnants that healed adhering to the femur, effectively crossing the joint, possess a small degree of knee stability. In this study, after resection of types 2 and 3 ACL remnants (i.e., attached to the femur), 12 of 67 knees (18%) demonstrated an increased ATT of 3 mm or more. However, when evaluating the knee stability in detail by using a navigation system, no statistical difference was noted in the ATT before and after resection of types 1, 2, and 4 ACL remnants at all knee flexion angles. Although the type 3 ACL remnants may function in knee extension, showing increased ATT after resection, according to our evaluation using the navigation system, the ACL remnants did not appear to play a major role in the stabilization of the knee.

Several biomechanical studies have shown that the fibers of the ACL show a distinct tension pattern. Zantop et al.[15] revealed the influence of isolated deficiency of the anteromedial (AM) or posterolateral (PL) bundle on the resulting knee kinematics in response to an anterior tibial load in the human cadaveric knee. The transection of the AM bundle resulted in a mean ATT of 5.3 (±0.6), 10.0 (±1.5), 15.9 (±1.8), and 12.7 (±2.0) mm at 0°, 30°, 60°, and 90° of knee flexion, respectively. An isolated transaction of the PL bundle showed a mean ATT of 6.0 (±0.5), 14.9 (±1.2), 10.7 (±2.0), and 8.3 (±0.7) mm at 0°, 30°, 60°, and 90° of knee flexion, respectively. This suggested that a resection of the AM bundle results in significantly increased ATT in response to an anterior tibial load at 60° and 90°. Furthermore, the results imply that resection of the PL bundle significantly increases the ATT at 30° of knee flexion. However, there were some patients who had obviously increased ATT at knee extension position after resection in our series, and no patients showed similar ATT before resection of the ACL remnants.

Recent interest has focused on partial ACL tears for performing selected and individualized augmentation of the AM or PL bundles. The importance of the ACL remnant has been recognized in terms of its proprioceptive and biomechanical functions and its vascularity, which may induce more rapid vascularization from the ACL remnant to the grafted tendon.[16–20] Adachi et al.[20] compared 40 cases of isolated AM or PL bundle reconstructions to a group of patients with complete ACL reconstruction. The ACL augmentation group showed significantly better AP stability and terminal stiffness than the ACL reconstruction group. The authors concluded that ACL augmentation, which can preserve ACL remnants with mechanoreceptors, is superior to ACL reconstruction from the viewpoint of position sense and joint stability. Therefore, the position of the intercondylar notch where the ACL remnant is attached, the condition of the remaining ACL fibers, and knee stability at the knee extension and flexion positions in the ACL reconstruction should be carefully noted prior to such surgery. Moreover, selective AM or PL bundle reconstruction may be considered for a partial ACL tear with persisting biomechanical function of the remaining ACL fibers.

Our study had certain limitations and weakness. First, the number of cases of each type was different, and the number of type 4 was especially small. Our small sample size inhibited us in identifying any correlations in ATT before and after resection, total rotation before and after resection, and ΔATT, potentially leading us to falsely conclude that there were none when in fact they were correlated. Second, the assessment of the ATT was based on the anterior tibial load alone, and the ATT of rotational instability was not evaluated. If the ACL remnant were reattached in the vicinity of the PL bundle footprint of the intercondylar notch, the rotational instability might be reduced, because the PL bundle is known to contribute to the rotational stability at the knee extension position. It is also necessary to clarify the biomechanical functions of ACL remnants to precisely evaluate the rotational stability of the knee.

Conclusions

The present study suggests that the ACL remnant does not play a major role in stabilization of the knee. Although type 3 ACL remnants significantly decreased anterior knee laxity in the knee extension position, the knee stability provided by the ACL remnants was not adequate.

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Figure caption

Figure 1: Arthroscopic findings of the ACL remnants (a-d). a, Bridging between the posterior cruciate ligament and tibia. (10 years after injury) b, Bridging between the roof of the intercondylar notch and tibia. (10 years after injury) c, Bridging between the lateral wall of the intercondylar notch and tibia. (5 years after injury) d, no substantial ACL remnants. (5 months after injury)

Figure 2: Schematics of the ACL remnants. a, type 1. b, type 2. c, type 3. d, type 4.

Figure 3: The average anterior tibial translation (ATT) and range of internal-external rotation (total rotation) before and after resection of ACL remnants. a, type 1. b, type 2. c, type 3. d, type 4. The average ATTs at 15° of knee flexion before resection of type 3 significantly increased after resection, but there were no significant differences in the average ATTs at any knee flexion angle within each type.

Figure 4: The degree of increased ATT at each knee flexion after resection (ΔATT). No significant differences in ΔATTs were observed within each type at any knee flexion angle.

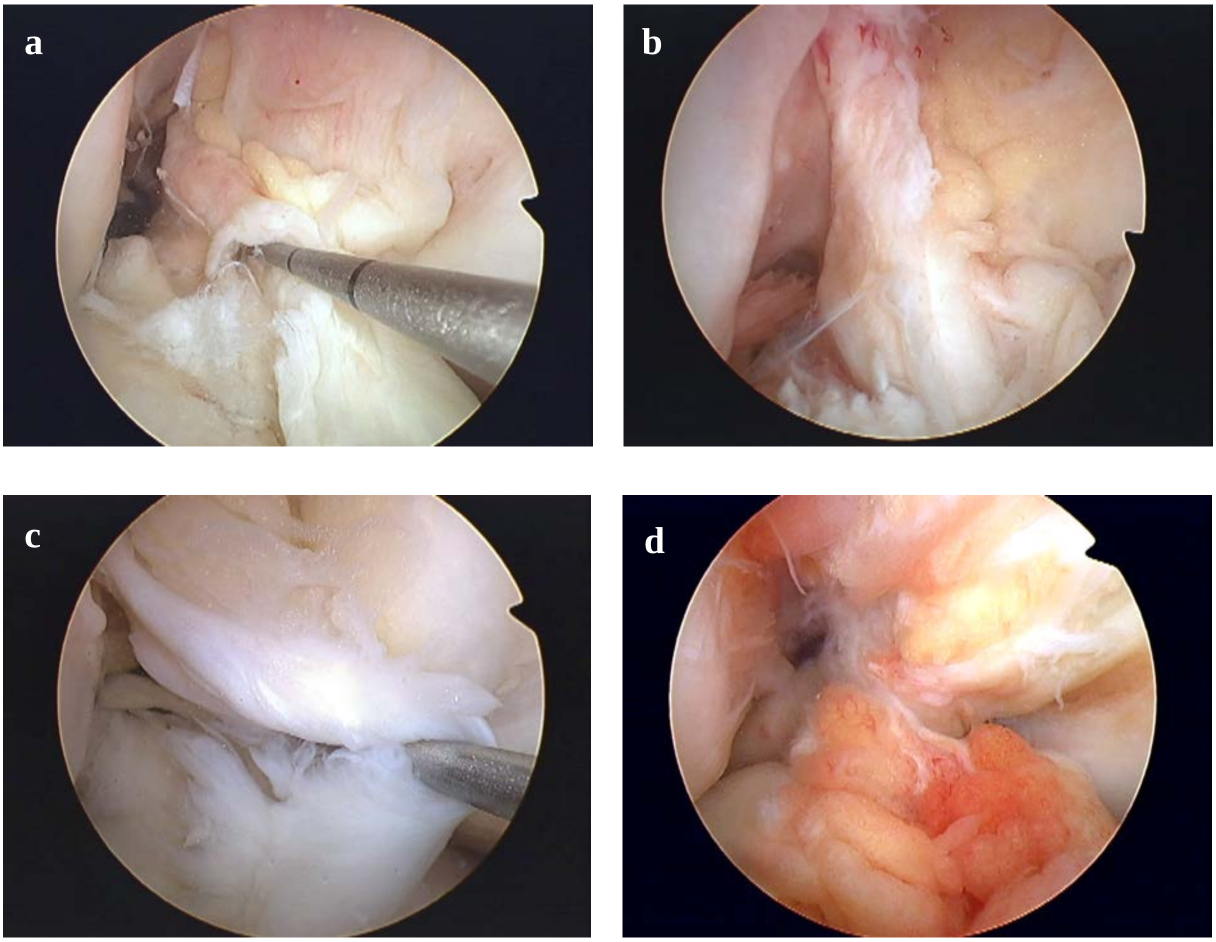

Figure 1a-d

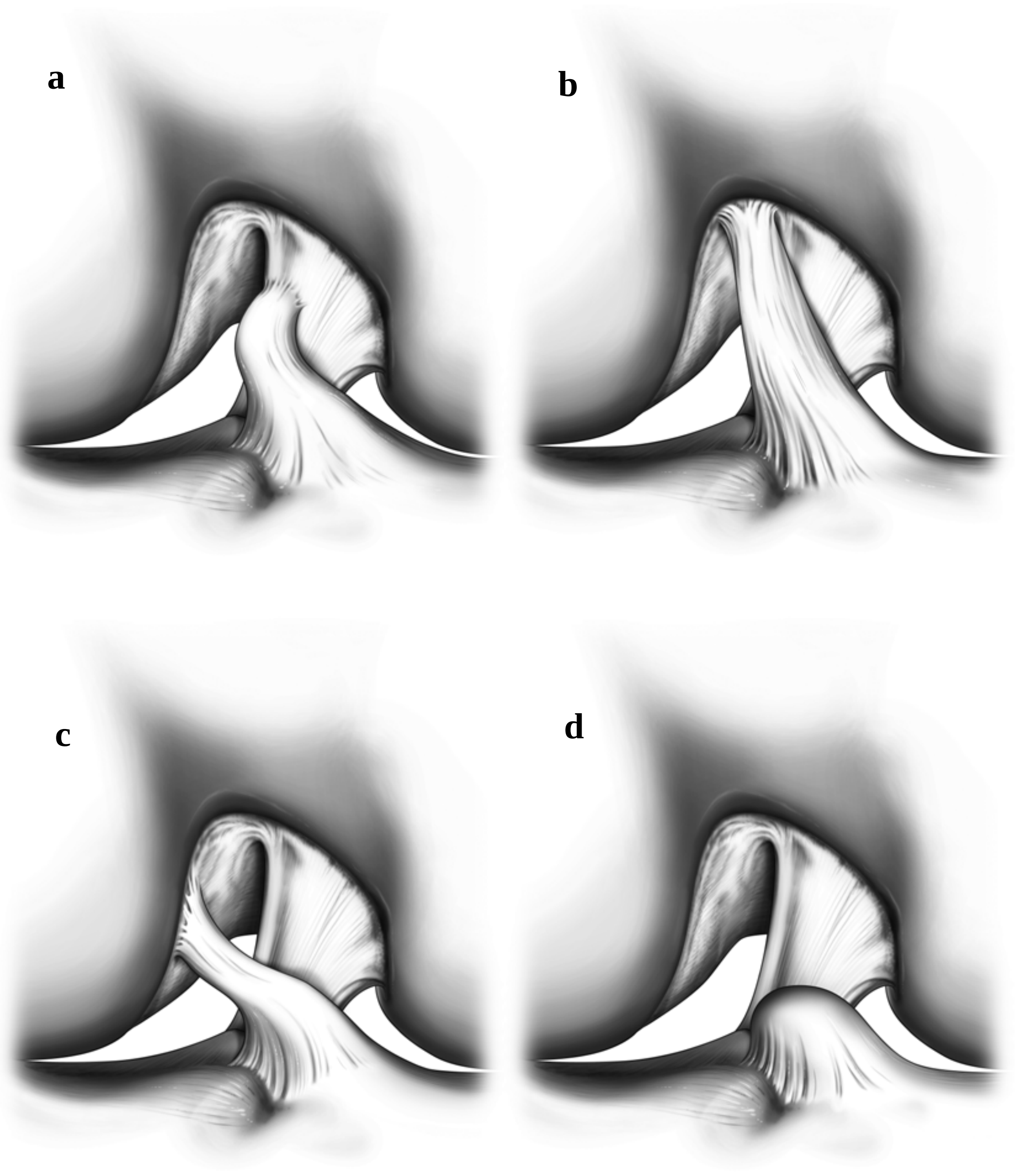

Figure 2a-d

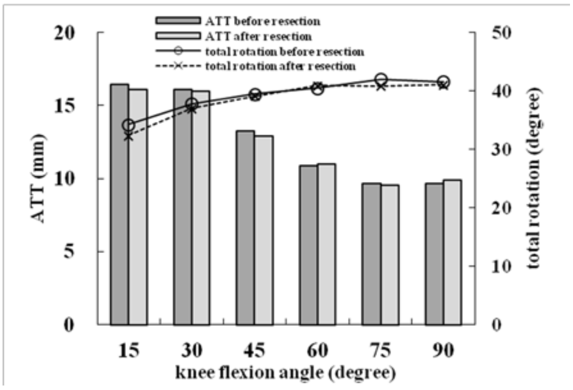

Figure 3a

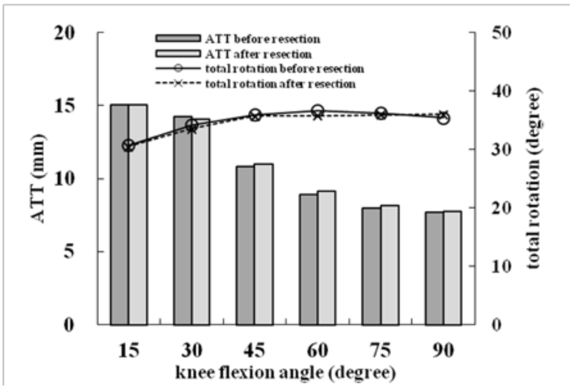

Figure 3b

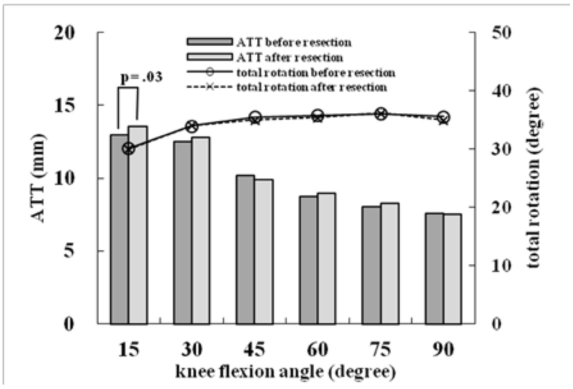

Figure 3c

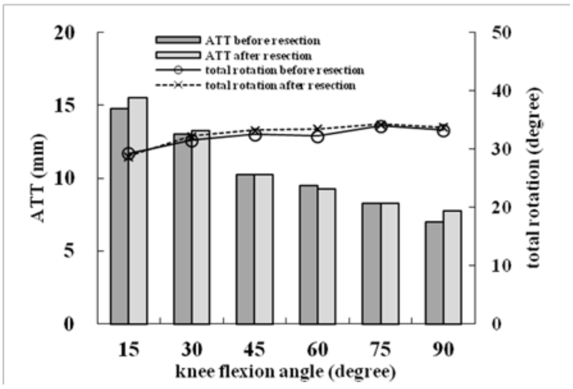

Figure 3d

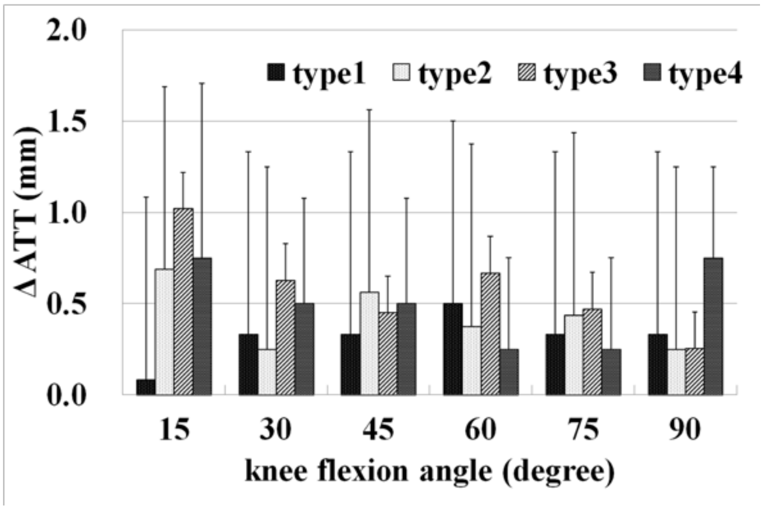
2.0
1.5
1.0
0.5
0.0
Δ ATT (mm)
type1
type2
type3
type4
15
30
45
60
75
90
knee flexion angle (degree)

Figure 4

Table 1

Anterior Tibial Translation Before and After Resection of the ACL Remnants

type	phase	knee flexion angle											
		15°	*P* Value	30°	*P* Value	45°	*P* Value	60°	*P* Value	75°	*P* Value	90°	*P* Value
type 1	Pre-cut	16.5 ± 3.0	.13	16.1 ± 2.8	.61	13.3 ± 3.2	.23	10.9 ± 2.4	.83	9.6 ± 2.5	.61	9.6 ± 2.1	.27
	Post-cut	16.1 ± 3.0		16.0 ± 3.0		12.9 ± 2.9		11.0 ± 2.5		9.5 ± 2.0		9.9 ± 2.2	
type 2	Pre-cut	15.1 ± 2.0	.87	14.3 ± 3.1	.42	10.8 ± 3.6	.56	8.9 ± 2.3	.79	8.0 ± 1.9	.60	7.7 ± 1.8	.75
	Post-cut	15.1 ± 1.8		14.1 ± 3.4		11.0 ± 3.1		9.1 ± 2.3		8.1 ± 2.0		7.8 ± 1.7	
type 3	Pre-cut	13.0 ± 2.7	.03	12.5 ± 3.0	.18	10.2 ± 3.3	.18	8.7 ± 2.9	.29	8.1 ± 2.6	.30	7.4 ± 2.4	.78
	Post-cut	13.5 ± 2.6		12.8 ± 3.1		9.9 ± 3.5		9.0 ± 3.7		8.3 ± 3.1		7.5 ± 2.4	
type 4	Pre-cut	14.8 ± 3.0	.21	13.0 ± 2.2	.63	10.3 ± 1.7	.80	9.5 ± 1.7	.63	8.3 ± 2.1	.39	7.0 ± 1.4	.06
	Post-cut	15.5 ± 3.4		13.0 ± 2.2		10.0 ± 1.2		9.3 ± 1.7		8.5 ± 1.7		7.8 ± 1.9	

ATT: anterior tibial translation

pre-cut: before resection of the ACL remnants

post-cut: after resection of the ACL remnants

P values are pre-cut vs post-cut.

Table 2

Total Rotation Before and After Resection of the ACL Remnants

type	phase	knee flexion angle											
		15°	*P* Value	30°	*P* Value	45°	*P* Value	60°	*P* Value	75°	*P* Value	90°	*P* Value
type 1	Pre-cut	34.3 ± 4.5	.17	37.8 ± 4.9	.24	39.5 ± 4.1	.29	40.5 ± 5.1	.63	42.0 ± 6.3	.15	41.6 ± 6.2	.24
	Post-cut	32.4 ± 5.4		37.0 ± 4.2		39.1 ± 4.4		40.9 ± 5.1		40.8 ± 5.5		41.1 ± 5.5	
type 2	Pre-cut	30.7 ± 3.3	.75	34.2 ± 4.1	.12	35.9 ± 5.1	.53	36.6 ± 5.1	.11	36.2 ± 4.1	.60	35.4 ± 4.8	.20
	Post-cut	30.5 ± 3.1		33.6 ± 3.6		35.7 ± 5.4		35.8 ± 4.7		35.9 ± 4.0		36.0 ± 4.6	
type 3	Pre-cut	30.1 ± 5.0	.66	34.0 ± 5.5	.76	35.5 ± 6.3	.11	35.8 ± 6.7	.33	36.1 ± 6.8	.87	35.6 ± 6.5	.45
	Post-cut	30.0 ± 3.8		34.1 ± 6.0		35.0 ± 6.6		35.4 ± 6.5		36.1 ± 6.7		35.0 ± 8.3	
type 4	Pre-cut	29.3 ± 4.5	.50	31.5 ± 4.8	.67	32.5 ± 4.0	.52	32.3 ± 2.9	.24	34.0 ± 2.9	.87	33.3 ± 4.3	.73
	Post-cut	28.8 ± 3.6		32.3 ± 2.4		33.3 ± 2.5		33.5 ± 1.3		34.3 ± 3.9		33.8 ± 3.1	

Total Rotation: range of internal-external rotation of tibia

pre-cut: before resection of the ACL remnants

post-cut: after resection of the ACL remnants

P values are pre-cut vs post-cut.